The Glacier and Land Ice Surface Topography Interferometer (GLISTIN): A Novel Ka-band Digitally-Beamformed Interferometer

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A Ka-band Digitally Beamformed Radar Interferometer for Topographic Mapping of Glaciers and Ice Sheets

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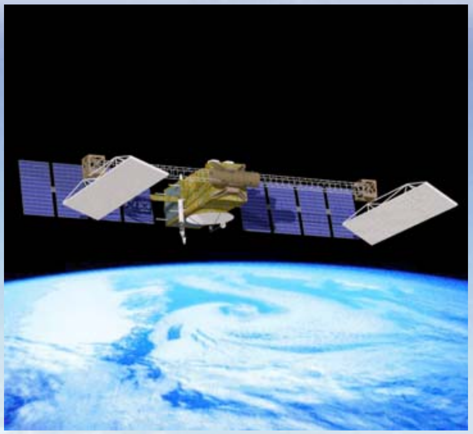
Objective

A high accuracy radar for ice topography mapping (both icesheets and glaciers) over a wide swath with sub-seasonal repeat intervals. The instrument is a Ka-Band digitally-beamformed interferometric synthetic aperture radar. The use of millimeter-wave signals increases accuracy, decreases mass and reduces snow penetration. Elevation digital beamforming preserves swath yet maintains high antenna gain on receive



Conceptual rendition of the deployed cross-track interferometer

Approach

- A mission design and trade study will be performed to define the antenna requirements
- Integration of the antenna from radiating elements to digitization
  - development of lightweight radiating elements
  - development of a small digital receiver
  - development of a phase-stable antenna array
- Demonstration of entire array will verify antenna, calibration and beamforming concept.

Key Milestones

- System/Science Requirements Document 4/06
- Radiating Element Design and Test 1/07
- L-Band Receiver Fabrication Complete 7/07
- Demonstrate Ka-band Downconverter 8/07
- Science Impact Assessment Report 1/08
- Radar Experimental Demonstration 8/08

TRL_{in} = 3 $TRL_{current}$ = 3

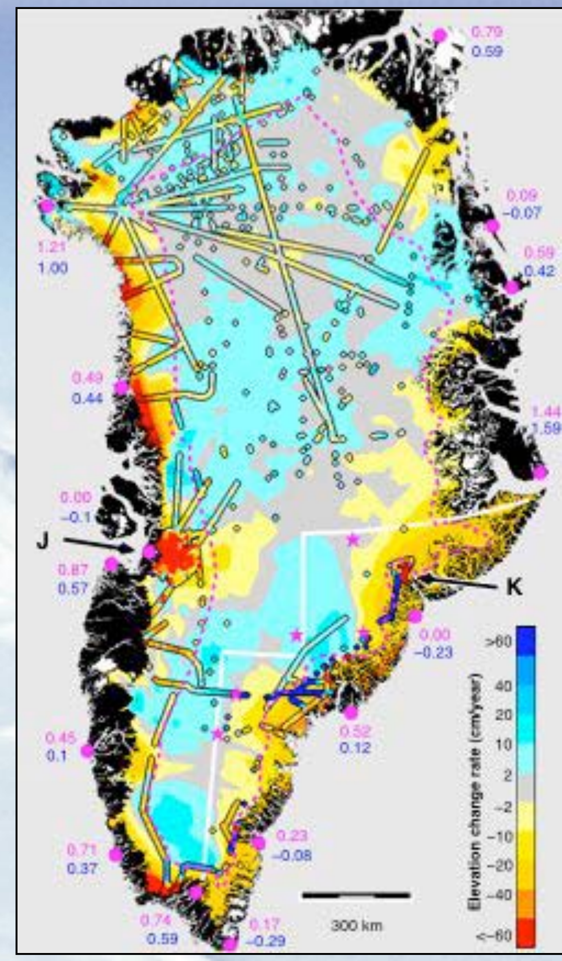
Co-Is: Greg Sadowy, Eric Rignot, Mark Zawadzki (JPL)

http://esto.nasa.gov

Scientific Motivation (1)

Fundamental question: "What changes are occurring in the mass of the Earth's ice cover"

- The Greenland and Antarctic ice-sheets together hold enough ice to raise global sea level by 80m
- The annual exchange of mass on the ice sheets is equivalent to 8mm/yr sea level=>any fluctuations in that level of exchange is significant on the global scale
- Changes in the polar region are rapid (years not centuries) and significant (meter-scale not millimeters)



Greenland ice changes 1997-2003. (Krabill, *et al)*

Scientific Motivation (2)

Current technologies limited to profiling airborne and spaceborne sensors (radar and lidar altimeters)

- Profiling techniques limited in swath coverage
- Airborne sensors impractical for global coverage
- IceSAT is an effective sensor, but unable to penetrate clouds and limited in swath

A radar mapping sensor impervious to cloud cover and is able to provide swath measurements at a variable spatial resolution consistent with the differing requirements of glacial vs ice-sheet mapping.

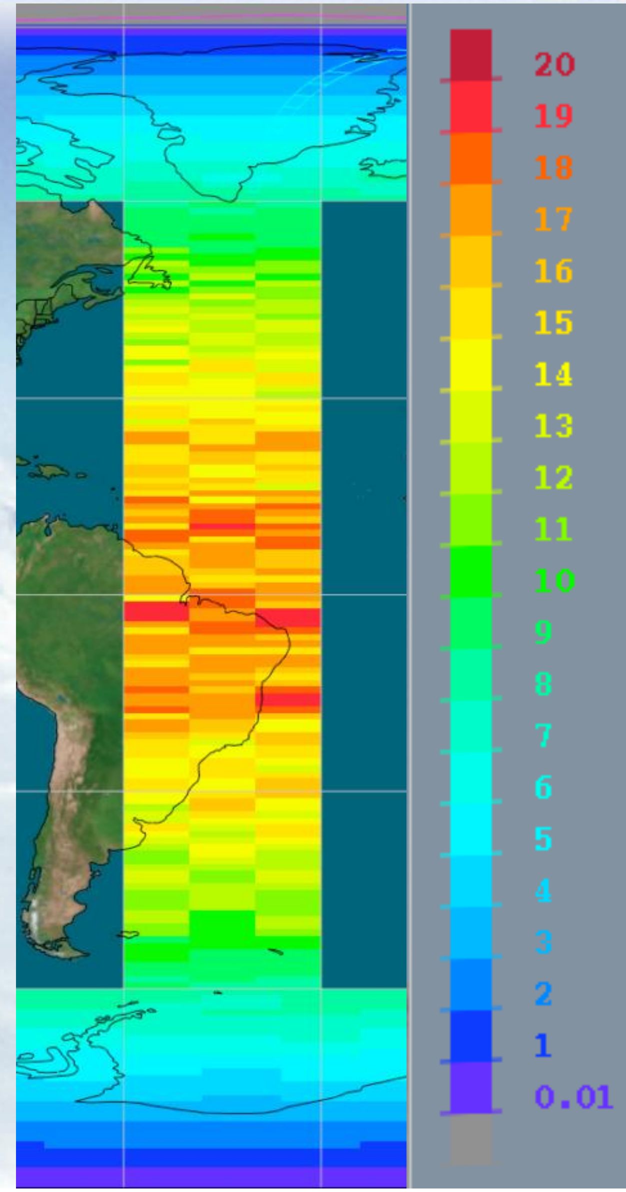
Topic	Req #	Requirement
Coverage	L2-CR1	Monthly to bi-monthly coverage of glaciers and ice sheets
	L2-CR2	Complete coverage of Greenland and Antarctica with North Pole hole.
Glaciers	L2-GR1	100 m x 100 m horizontal resolution for glacier height measurements.
	L2-GR2	100 m x 100 m horizontal posting for glacier height measurements.
	L2-GR3	1 m relative height error for glacier measurements
Ice Sheet	L2-IR1	1.0 km x 1.0 km horizontal resolution for ice sheet measurements.
	L2-IR2	1.0 km x 1.0 km horizontal posting for ice sheet measurements.
	L2-IR3	10 cm relative height error for ice sheet measurements.

Orbit Selection

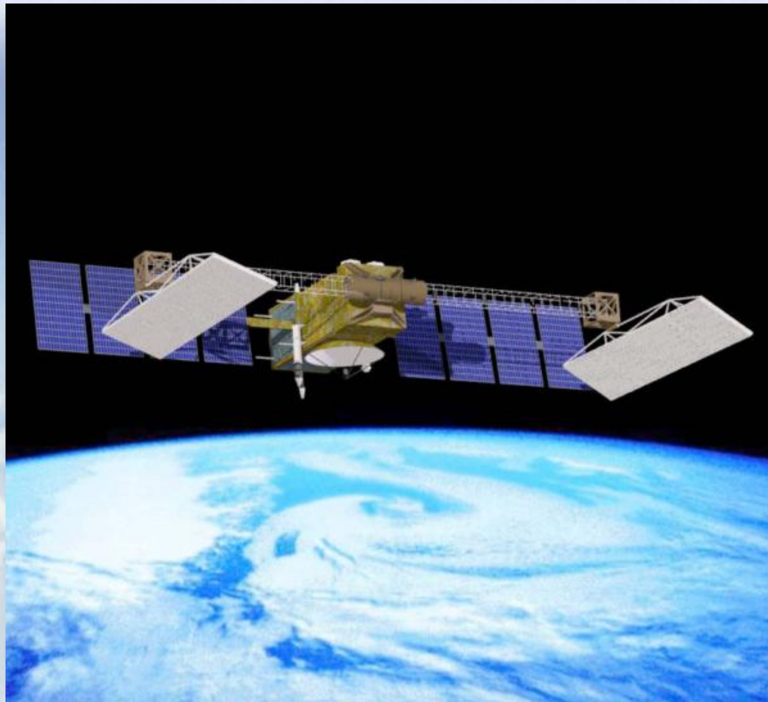
- Given:
  - Altitude close to 600 km
  - Incidence angle range: 18.6 to 25.2 deg.
  - => Swath extends from 184 to 256 km on one side of the ground track
- Requirements:
  - Coverage of South Pole
  - Accessibility of all land-ice.
  - Hole around North Pole is acceptable.
  - Requirement: Monthly to bi-monthly acquisitions
- **Best altitude/orbit count: 605.7 km, 593 orbits per repeat cycle, 40 days to repeat**
- **Chosen orbit: 92 deg inclination, left looking (based on above & crossover separation)**

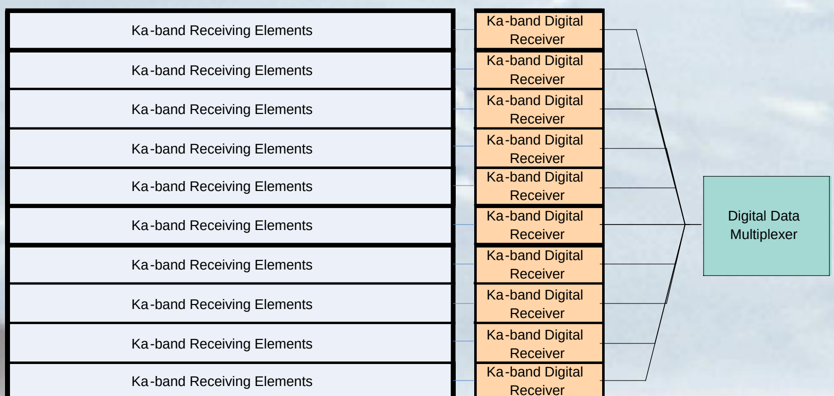
Near right: Sun-synchronous orbit is not acceptable: gap from -85.1 to South Pole

Far right: Average temporal gap between successive revisits



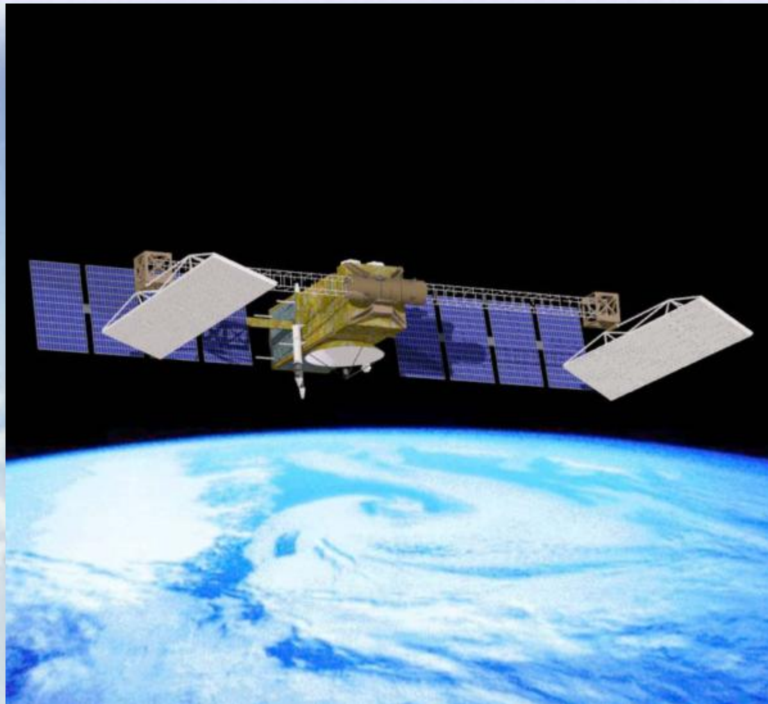
System Design Overview

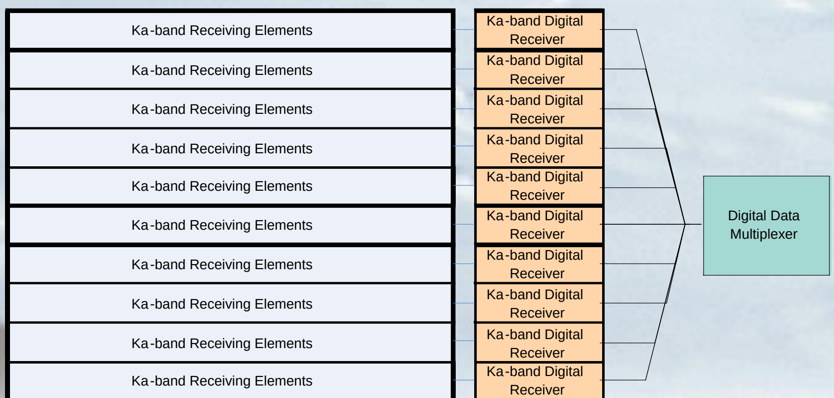




- A Ka-band InSAR system can meet the science requirements
  - 70 km swath
  - 600 km altitude
  - 10 cm height error at 1 km x 1 km resolution
- Ka-Band is chosen for two reasons:
  1. Insensitive to cloud cover, yet minimizes snow penetration
  2. A high (mm-wave) frequency allows us to maintain high accuracy with a smaller baseline
- Problems with previous mm-wave InSAR
  - high transmit power requirements and
  - limited swathwidth (large antennas required for high-gain leading to reduced swathwidth).
- We apply digital-beamforming to a large array on receive to maintain high gain, yet at achievable transmit powers.
  - Approximate 12-fold saving in transmit power for same swath-width.

Key System Parameters





Parameter	Units	Quantity
Peak Transmit Power	kW	1.5
Frequency	GHz	35.75
Bandwidth	MHz	40
Antenna Length	m	4
"stick height"	m	0.063
Number of sticks	#	16
Total array height	m	1.01
Pulsewidth	us	25
Prf	kHz	4
Interferometric baseline	m	8
Polarization	-	Horizontal
Swath-width	km	70
Incidence angle range	deg	18.6 - 25.2
SNR over swath	dB	3.0-10.0

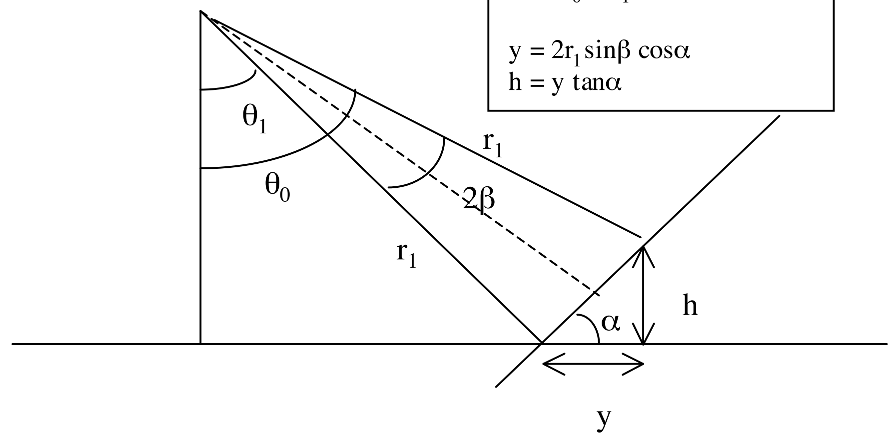
System Design Issues

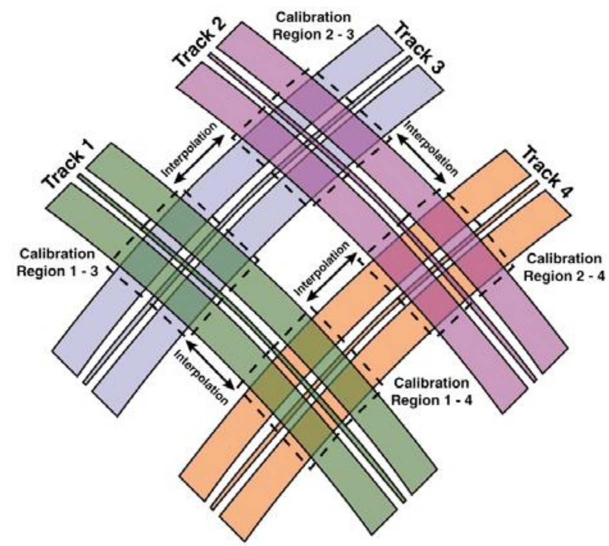
- Grating Lobes:
  - have limited the number of “sticks” to 16 creating an inter-stick spacing of ~7.4λ
  - we have grating lobes at ~+/- 7 degrees.
  - When beamforming off-nadir the grating-lobe levels become significant
  - we are able to range-gate out the ambiguous returns.
- Stringent Antenna Location Knowledge Requirements
  - requirements are extremely stringent: i.e. baseline roll must be known to 0.25 arcsec
  - WSOA demonstrated that such stringent requirements could be met through cross-over calibration techniques
  - We can apply this technique to GLISTIN (a topic of ongoing work)

For the returns from the grating lobe to arrive at the same time as the main lobe:

$\alpha = (\theta_0 + \theta_1)/2$
$\beta = (\theta_0 - \theta_1)/2$

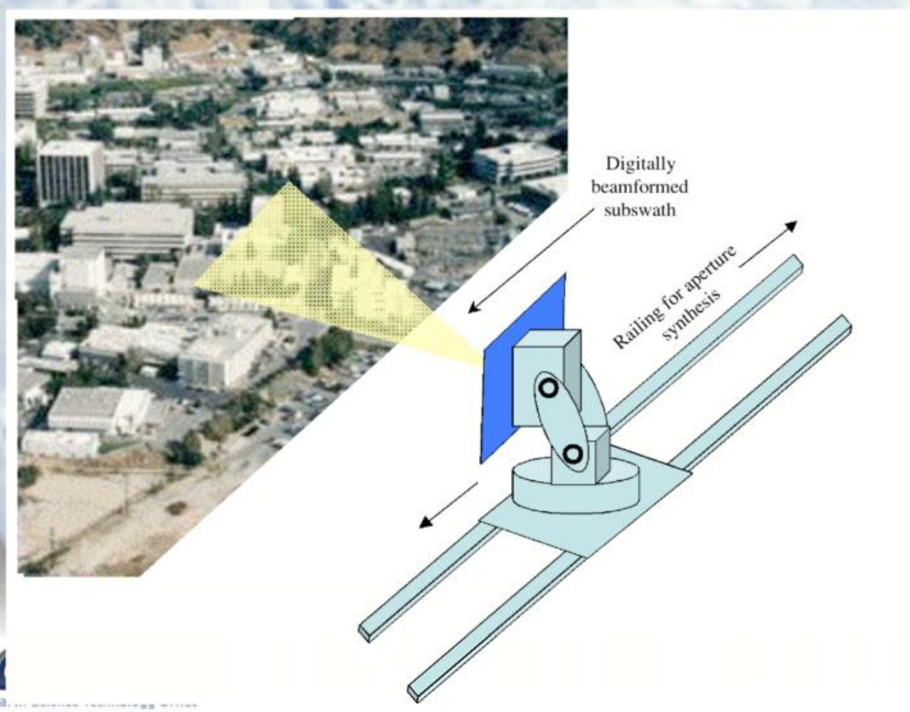
$y = 2r_1 \sin\beta \cos\alpha$
$h = y \tan\alpha$





Demo Overview

- The main objective of this program is to demonstrate key technology (Ka-band DBF antenna) & associated processing
- Where possible the requirements for the key technology items are that of the spaceborne design.

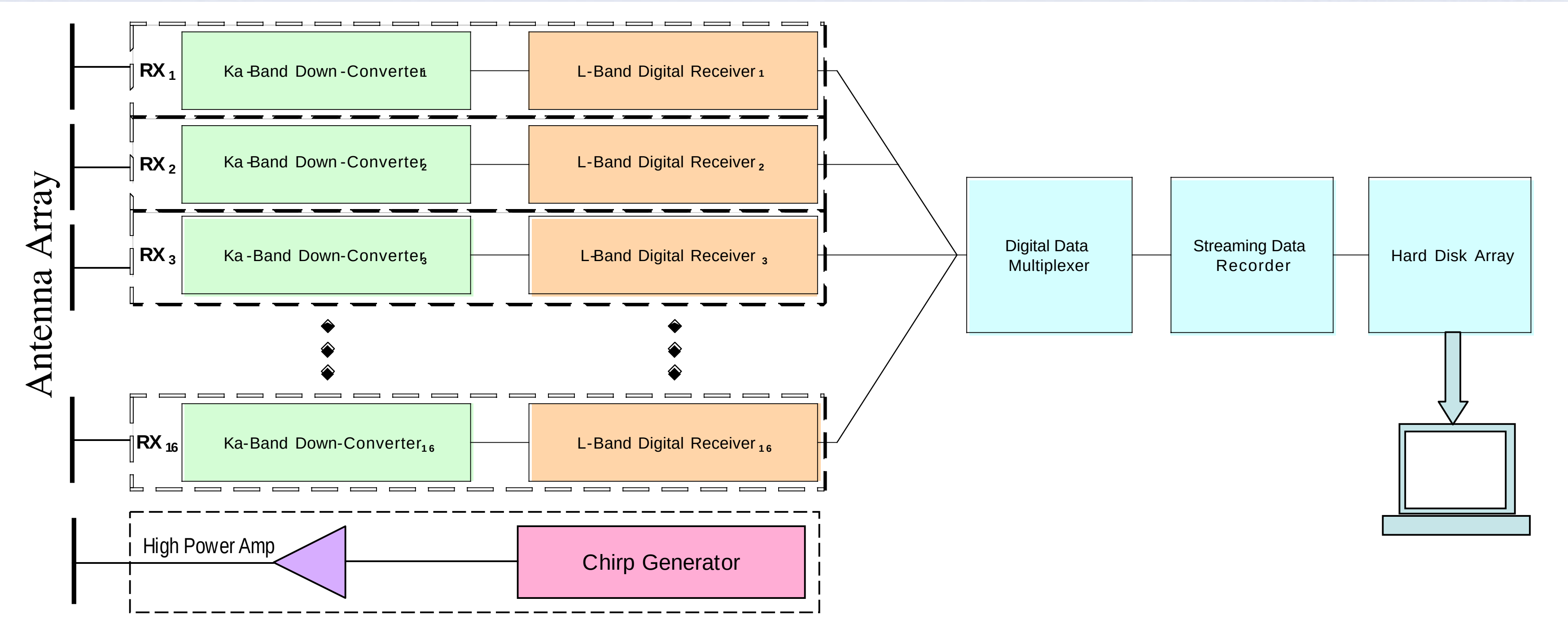


<u>Demo Overview</u>

We will use the JPL mesa antenna range to characterize and then demonstrate the calibration and performance of the antenna array and the entire end-to-end concept for the DBF interferometric image synthesis.

- The simple radar system will be mounted on a railing overlooking JPL and rotated in azimuth on the positioner to form an image
- DBF will be used to scan in elevation on a fine-scale coupled with elevation scanning on a coarse-scale using the positioner
- A 0.5m interferometric baseline will be achieved by halving the effective aperture - sufficient at the close range of operation

Demo Block Diagram & Technology Matrix



Subsystem / Component	Key Technology
Antenna Aperture	Slotted Waveguide
Ka-band Electronics	mm-wave hybrid microelectronics
L-band Digital Receiver	Atmel ADC + Xilinx FPGA
Data Acquisition	COTS

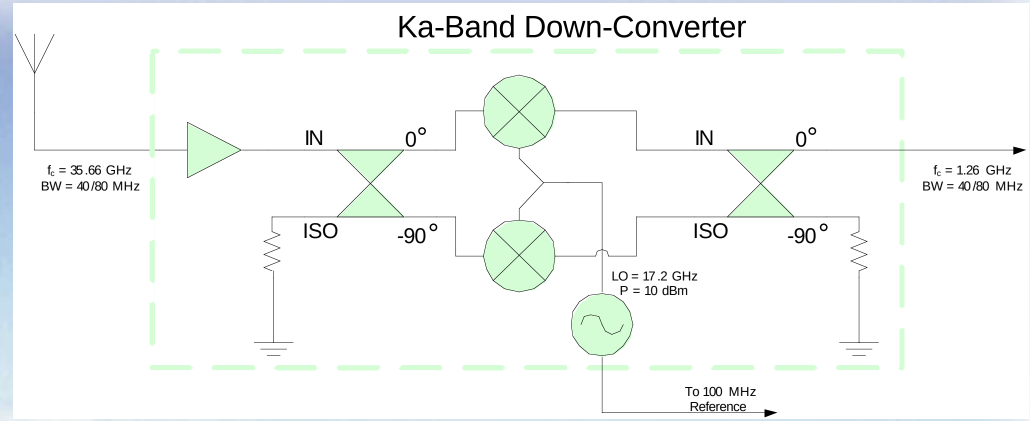
Technology Detail: Antenna

Demonstrate a 1 m x 1m Array (ie 1/4 of the spaceborne antenna size) → a 160 x 160 slot array

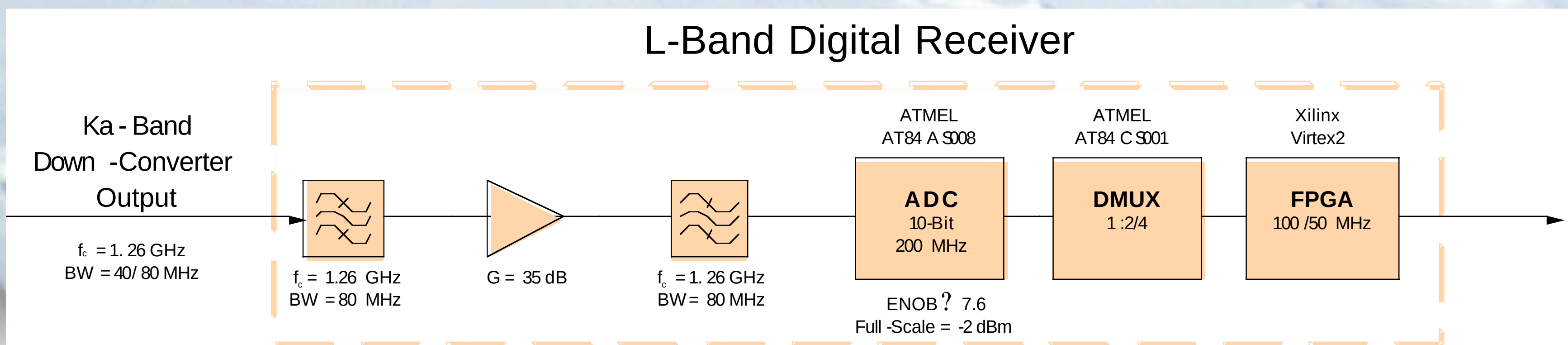
- pushes fabrication limits for such a large array at Ka-band
- vendor recommended subdividing fabrication modules to 40x80, requiring a total of eight for assembly of the 1m x 1m array
- make two 10x40's this year to work out fab and electrical details

Technology Detail: Digital Receiver

- Ka-Band Down-Converter Element
  - Down-Converts Input Ka-Band Signal to L-Band
  - Utilizes Image-Rejection, Even-Harmonic Mixer
  - To be Procured as a Single, Connectorized Component



- L-Band Digital Receive Element
  - Filters Out Undesired Portion of Input Spectrum
  - Adjusts Signal to Proper Level for Sampling
  - Bandpass Sampling of L-Band (Direct Digitization)
  - DMUX Data to Slow Operating Frequency Requirement of FPGA
  - Utilize FPGA for Buffering of Data and to Communicate with Data System

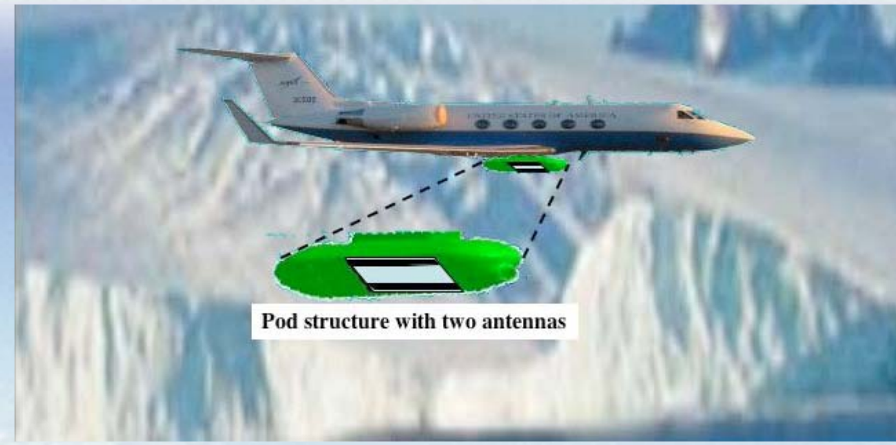


Further Opportunities

International Polar Year Proposal

Investigators: Delwyn Moller, Greg Sadowy, Eric Rignot, Marc Simard, Scott Hensley (JPL)

Collaborators: Prof. Koni Steffen (Univ. of Colorado), Dr. William Krabill (NASA/GSFC)



A proposal to the International Polar Year NRA has been submitted for which we propose to adapt the ESTO UAVSAR system to operate in a single-pass interferometric mode. Our approach is to heavily leverage ESTO technology already developed :

- An ESTO IIP-developed Ka-band upconvert/downconvert chain is added to the L-band system
- The two polarimetric channels of UAVSAR are used for the two interferometric channels
- The L-band antenna panel is replaced with two 1m slotted waveguide antennas using the same technology as the GLISTIN antennas. The baseline is limited by the pod accommodation to approximately 0.5m
- The UAVSAR data-acquisition system and processing infrastructure is already capable for this application

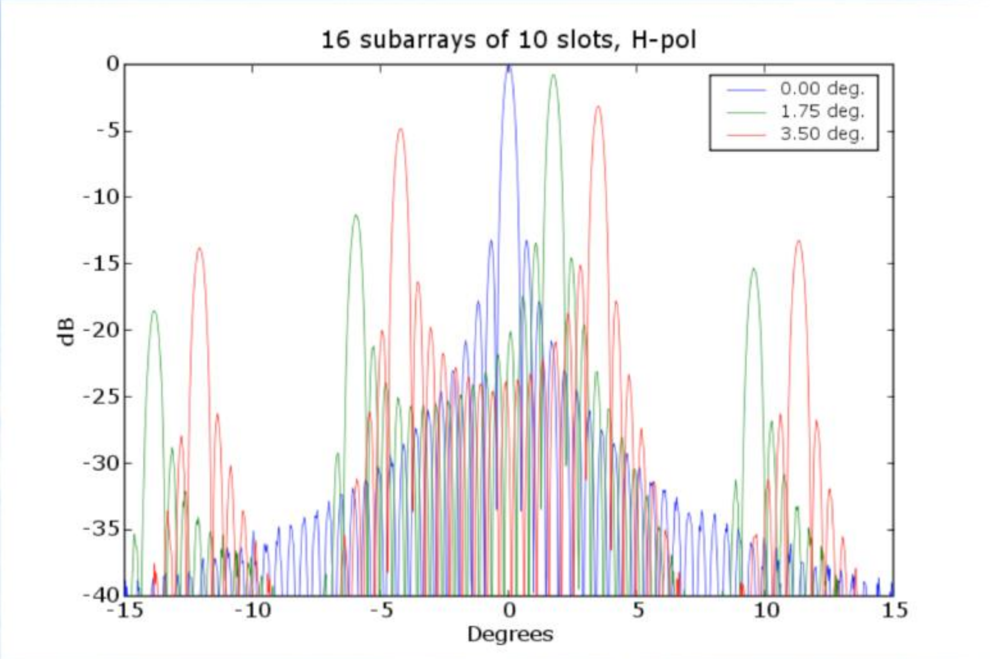
Objectives:

1. To demonstrate single-pass Ka-band interferometry and calibration
2. To characterize the penetration depth of Ka-band into snow cover as a function of snow wetness and incidence angle. Critical to the feasibility of a future GLISTIN ice-topography mission
3. To collect a cohesive mosaicked topographic map over Jakobshavn glacier (Greenland) in collaboration with IPY scientists

Backup Material

Grating Lobes due to "Inter-stick" spacing

- In order to avoid grating lobes an array must be critically sampled in space (i.e. interelement spacings of λ /2 or less)
- An array response is the product of the element pattern times the array pattern - therefore the element pattern can be used to reject grating lobes in non-critically sampled arrays. However - if the array is steered off-nadir, the element pattern stays static but the array pattern shifts decreasing the grating lobe rejection
- In the case of GLISTIN - we have limited the number of "sticks" to 16 creating an inter-stick spacing of ~7.4 λ => we have grating lobes at ~+/- 7 degrees. When we digitally beamform off-nadir the grating-lobe levels become significant - however we are able to range-gate out the ambiguous returns.

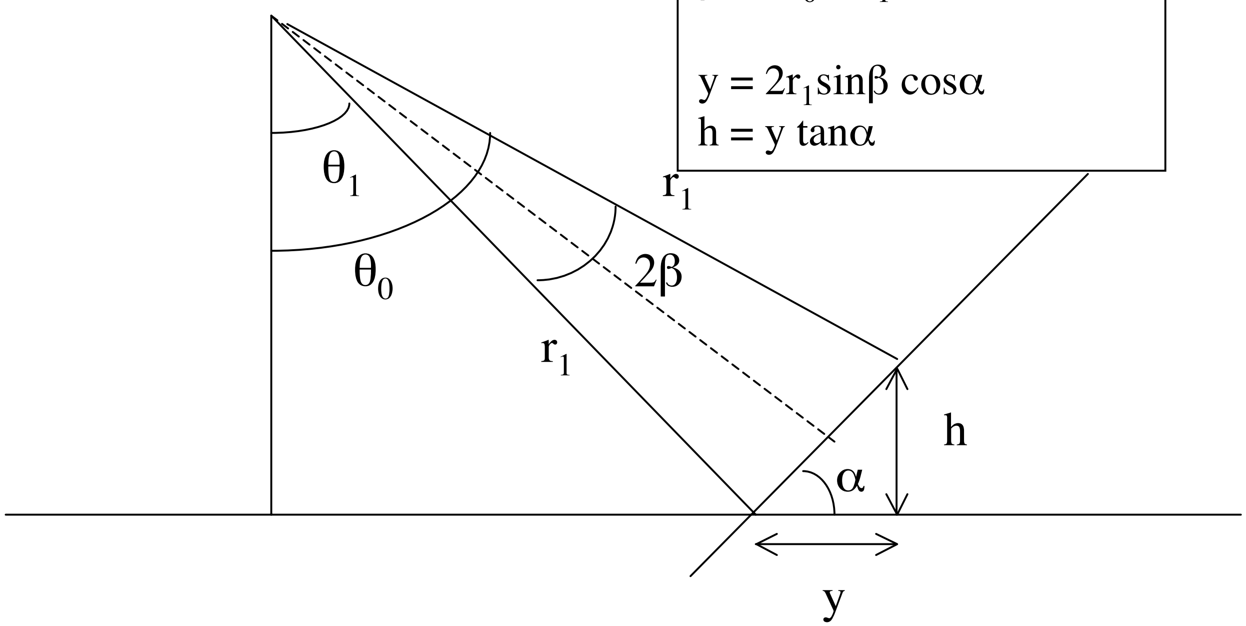


Range Ambiguities Due to Surface Slopes

For the returns from the grating lobe to arrive at the same time as the main lobe:

$\alpha = (\theta_0 + \theta_1)/2$
$\beta = (\theta_0 - \theta_1)/2$

$y = 2r_1 \sin\beta \cos\alpha$
$h = y \tan\alpha$



Number of Slots (0.74λ)	Grating lobe separation	Critical Slope (@ max θ_0)	Critical Distance	Δheight
10	7.7 °	18.2 °	42.4 km	13.9 km

Assumptions: $\theta_0 = 23^o$, $h = 600km$

Systematic Errors & On-orbit Calibration

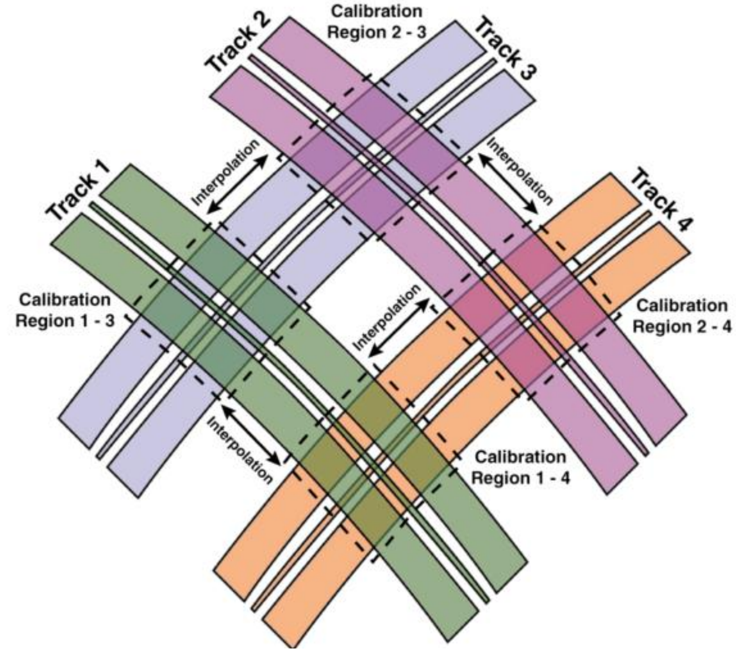
Systematic error budget required to meet science requirements is extremely challenging:

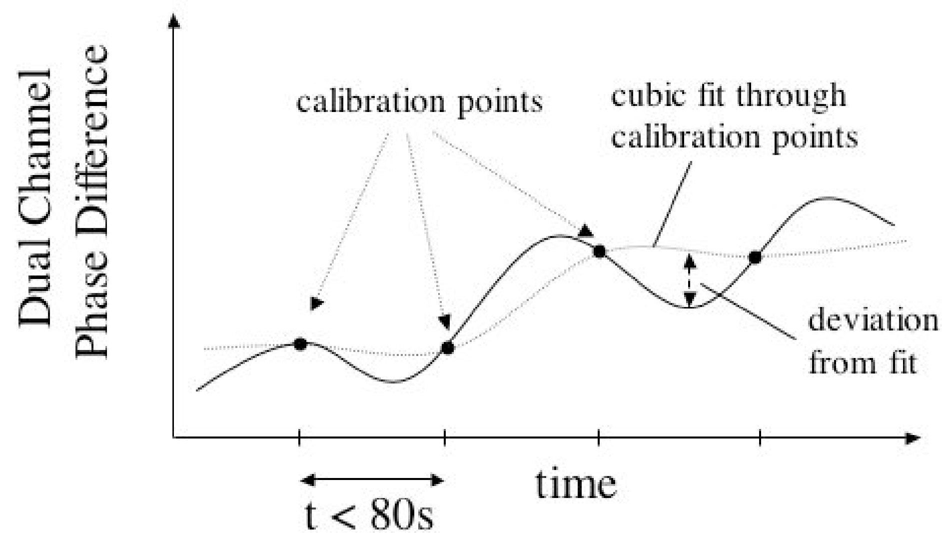
#	Requirement Statement	Value	Unit
L3-SY1	The baseline roll shall be known to within	0.025	arcsec
L3-SY2	The antenna phase mismatch shall be known to within	0.025	deg
L3-SY3	The receiver phase mismatch shall be know to within	0.04	deg
L3-SY4	the basline dilation shall be known to within	2.00	um
L3-SY5	the ADC system timing shall be accurate to	0.035	ns
L3-SY6	The spacecraft attitude shall be known to within	0.025	arcsec
L3-AP1	Each GLISTIN antenna shall have a boresight elevation pointing angle of	20.5 +/-0.5	deg

The Wide Swath Ocean Altimeter (WSOA) demonstrated through significant analysis and simulation that such stringent requirements could be met through the use of on-orbit self calibration scheme using nadir altimeter tracks

WSOA Calibration Strategy

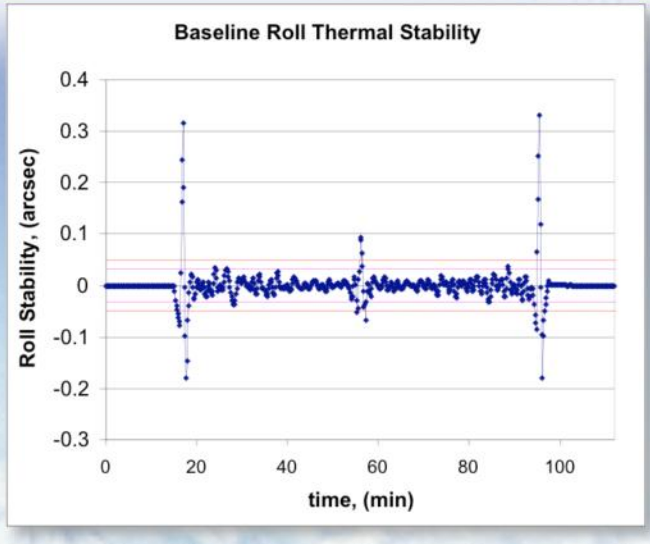
- WSOA assumed no change in the (incoherent) height between ascending & descending passes
  - Time between ascending / descending cross-over points less than +/- 5 days
- Use the ascending altimeter track (not subject to roll & phase errors) to calibrate the descending WSOA interferometer track at each crossover
- Interpolate between crossovers (no more than 80 seconds apart)
- Resultant requirement is on the *residual* after removal of the interpolated fit



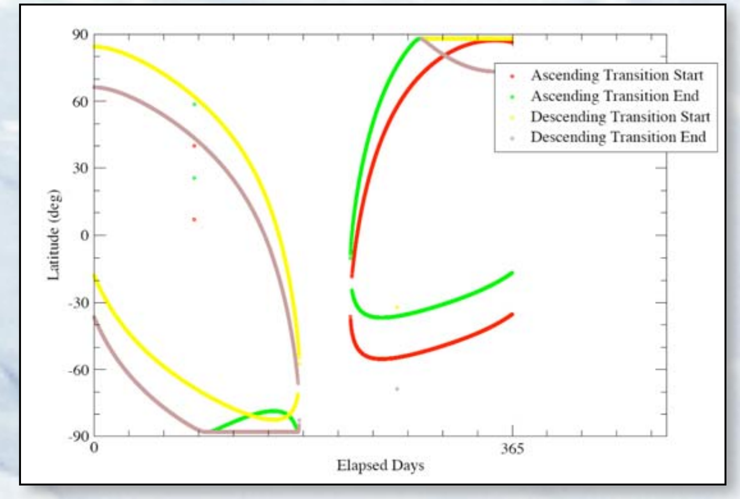


WSOA Lessons Learned & Go Forward Plan

- During WSOA we learned that the stringent residual systematic error requirements were typically met (with 80 second crossovers) at all points outside of eclipses
- During the next phase of the GLISTIN IIP, work will focus on:
  1. Understanding "time between crossovers" based on re-analysis of WSOA deformation data, both near & far from eclipse points
  2. Determining appropriate calibration approach over ice using combination of sea surface at coast, data from previous passes over different points on the ice sheet, etc.
- Data near eclipse points can conceivably be neglected if self calibration is not feasible
  – This was the approach adopted by WSOA



Profile of baseline roll after fit removal showing jumps at eclipse points



Eclipse latitude over 1 year